Electrical resistivity of the mantle at the South American subduction system in Northern Chile.

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Introduction

In order to investigate the electrical resistivity of the upper mantle and mantle transition zone at the South American subduction system in North Chile we use data from the magnetotelluric (MT) network of the Integrated Plate Boundary Observatory Chile (IPOC). The IPOC is a permanent array of geophysical and geodetic multi parameter stations located in the Coastal Cordillera and Longitudinal Valley in Northern Chile. MT data is gathered at nine of the nineteen observation sites, with an average site spacing of approximately 50 km. The IPOC is operated since 2006 by the GFZ German Research Centre for Geosciences.

From long term observations of electromagnetic fields at two MT monitoring sites we compute MT transfer functions in the period range between 10 and 100,000 seconds. 2D forward modelling indicates that the apparent resistivities and phases at periods between 20,000 and 100,000 seconds are sensitive to the electrical conductivity structure of the upper to mid mantle. We present preliminary 2D inversion results which reveal a drastic decrease of electrical resistivity by two orders of magnitude between 100 and 250 km depth. Between 250 and 400 km depth the electrical resistivity decreases by another order of magnitude.

Data

The set-up of an IPOC MT monitoring site consists of a three component long period fluxgate magnetometer (GeoMagnet) and non-polarizing Ag/AgCl electrodes to measure all three components of the magnetic field and both horizontal components of the electric field. The monitoring sites (Figure 1) are connected via satellite link to the GFZ in Germany. The objective of the project is to monitor and analyse electromagnetic data to decipher possible temporary changes in the subsurface resistivity distribution, e.g. as a consequence of large scale fluid relocation.

Due to the extreme dry ground of the Atacama Desert continuous monitoring of the electric field is difficult. Contact resistances are on the order of MΩ and electrolyte is leaking. After a range of tests with various electrode installations we found a solution in December 2010. A plastic tube is buried vertically in the ground. At the bottom it is open and filled with a layer of bentonite where the electrode is pressed in. The space above is filled with water and serves as reservoir. The top is sealed with a lid.

We processed MT data of 150 subsequent days using the EMERALD processing package (Ritter et al. 1998). The resulting

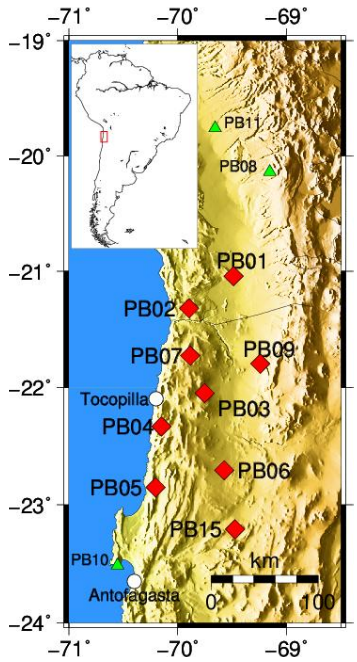

Figure 1: The IPOC-MT network in Northern Chile with sites PB01 to PB07, PB09 and PB15 (red symbols). The green symbols indicate locations of multi parameter sites without an MT component.

apparent resistivity and phase curves range from periods of 10 s to 100,000 s. We chose sites PB01 and PB09 for this study because the sites have relatively good data quality in both, the XY- and YX-components (Figure 2).

At both sites the YX component of apparent resistivity and phase exhibits smooth variation and small errors at periods longer than 10,000 s, at PB09 even 100,000 s are covered. In contrast, the XY component is usable only from approximately 20 to several thousand seconds.

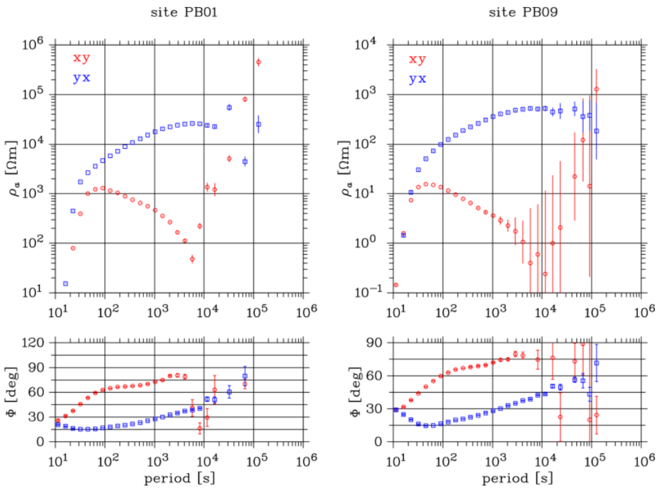

Figure 2: Apparent resistivities and phases for sites PB01 and PB09.

Depth resolution and directional dependency

To test the sensitivity of the MT data to certain depth ranges, we used 2D forward modelling using the software package WinGLink (Mackie et al. 1997). A 2D approach is necessary as the XY and YX components of apparent resistivity split up (Figure 2) in a way which is typical for the coast effect and which cannot be explained with 1D modelling.

We created an east-west orientated 2D background model including topography and ocean (not shown) and calculated the forward response at two synthetic sites which represent the minimum and maximum distance of the IPOC MT sites to the coast (A-150 and A-240 resembles sites PB01 and PB09, respectively). Background resistivity is set to 100 Ωm and the

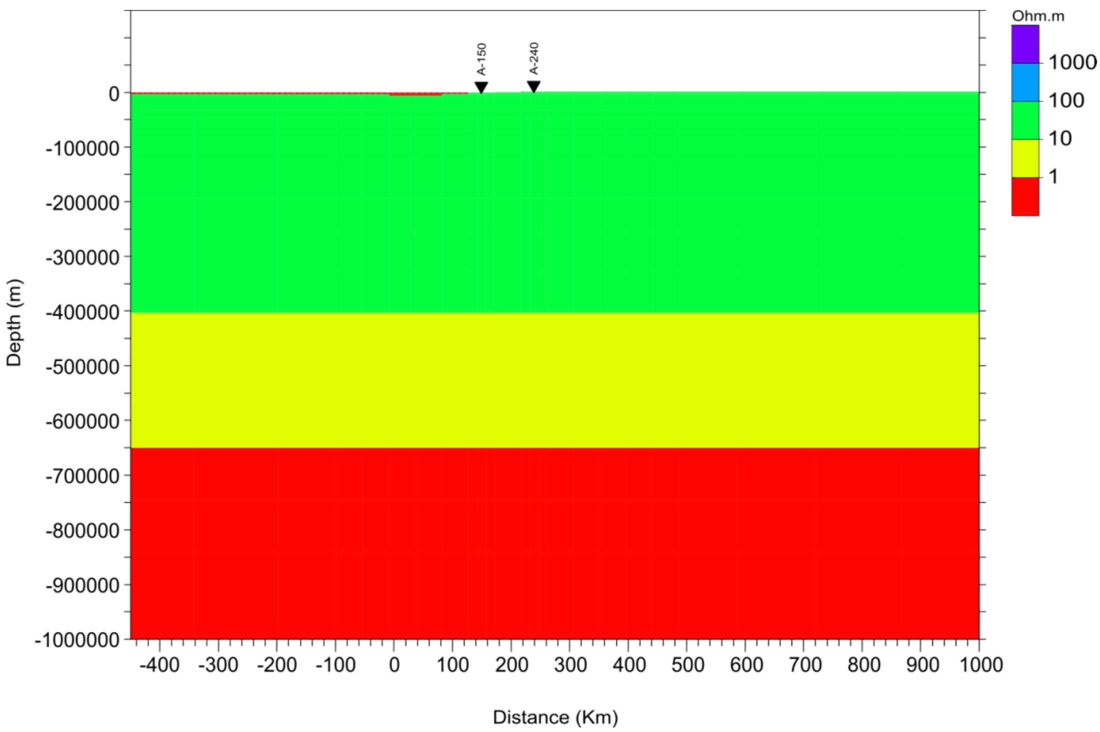

Figure 3: The 2 D forward model includes electrical resistivity structures which represent phase transitions in the mantle according to Utada et al. (2003). The distance to the coast of the two synthetic sites is similar to IPOC sites PB01 and PB09.

ocean to 0.3 Ωm. Figure 4 (upper panels) shows resulting apparent resistivity and phase curves which exhibit the expected split up between TE (XY component) and TM (YX component) modes. The split up is larger at the site closer to the coast.

In an alternative model we include two horizontal resistivity layers at 400 and 650 km depth with 10 and 1 Ωm, respectively (Figure 3). These discontinuities of electrical resistivity in the mantle were observed by Utada et al. (2003). These deep conductors are interpreted to reflect mineral phase transitions from olivine (α-phase) to wadsleyite (β-phase) and from material of the upper mantle to silicate perovskite or magnesiowüstite of the lower mantle, respectively. Comparing apparent resistivities and phases generated by the background model (Figure 4, upper panels) to those of the model including conducting layers at mantle depths (Figure 4, lower panels),

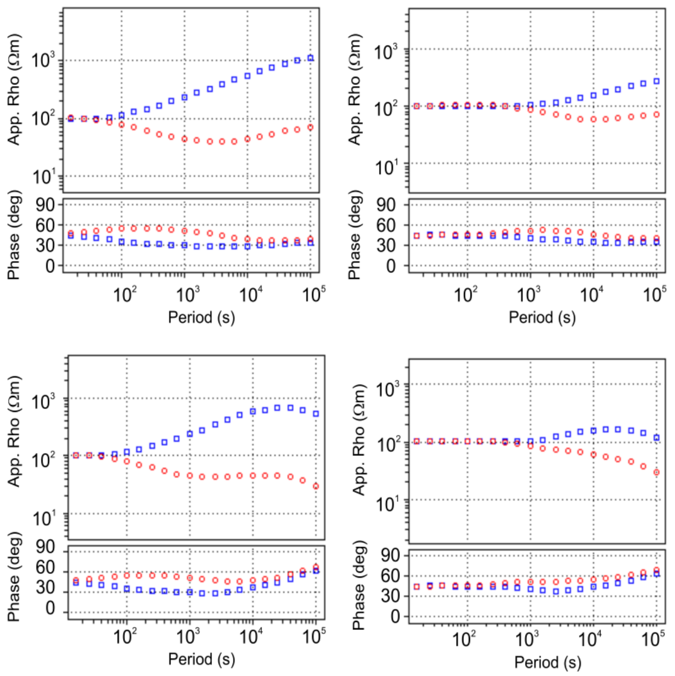

Figure 4: 2D forward model results for a simple 2D model featuring an conductive ocean in a homogeneous background (upper panels) and a model which includes two conductive layers in the mantel (lower panels). The left hand sides show results of site A-140 (PB01), the panels to the right show results of A-240 (PB09).

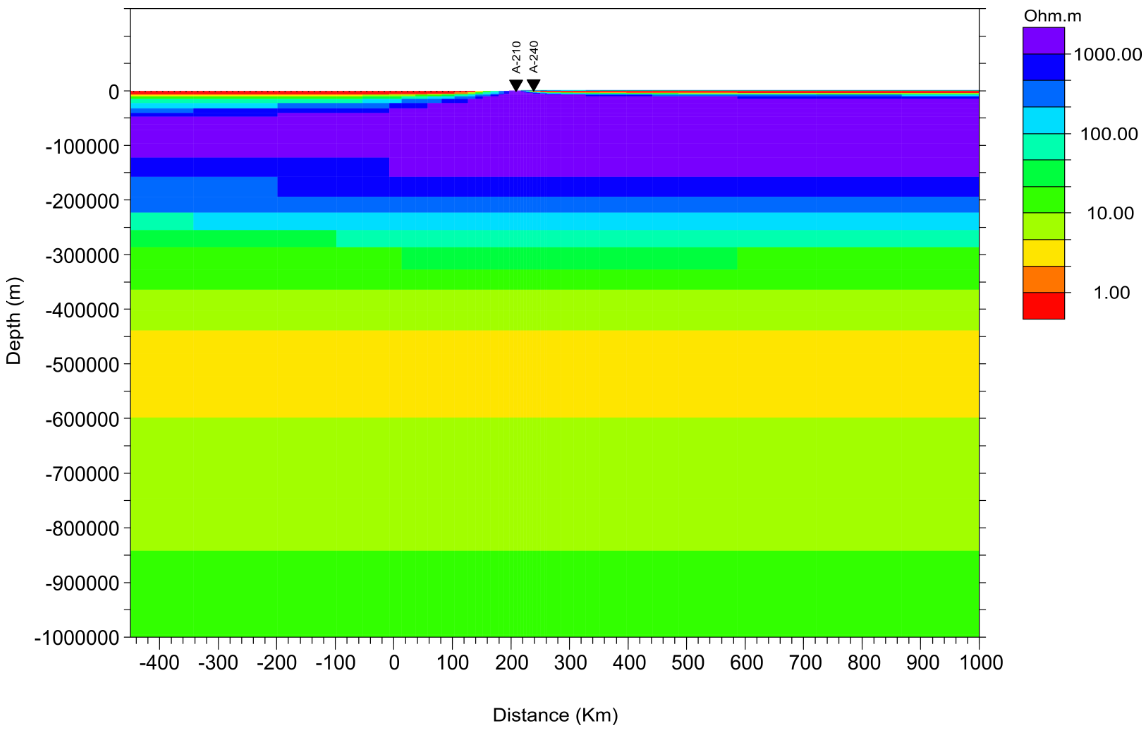

Figure 5: Preliminary result of inversion of apparent resistivity and phase of two sites. We inverted for TE and TM mode apparent resistivity and phase.

confirms that the influence of the deep structures (> 400 km) is observed at periods above 20,000 seconds and affects both, the TE and the TM mode.

2D Inversion

To test if a phase transition zone in the mantle can be detected with the long term recordings of MT data in northern Chile we carry out a 2D inversion of apparent resistivities and phases for the IPOC sites PB01 and PB09. As a starting model we used a homogeneouse background with a conductive ocean. The distance of the sites to the coast is similar to PB01 (A-210) and PB09 (A-240). For the inversion we fixed the position and resistivity of the ocean. Unresolved TE mode data at longer periods are masked prior to the inversion. To attenuate the scattering of apparent resistivity and phase curves at the longest periods we smoothed the data.

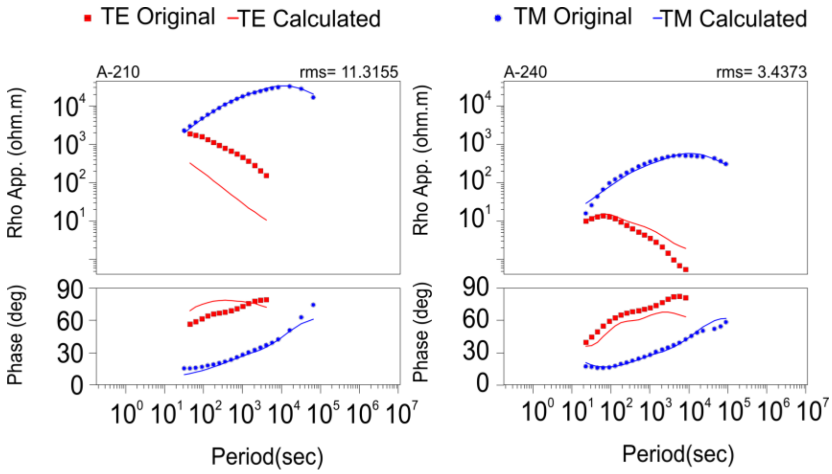

Figure 6: Data misfit of 2D inversion of sites PB01 and PB09, using a conductive ocean in a homogeneous background as starting model. The fit of the TM mode is better than the fit of the TE mode, which is noisy at long periods.

Figure 5 shows the inversion result after inverting apparent resistivity and phase of TE and TM mode. The error floors were set to 10 % for apparent resistivity and 2% for phase data. After 200 iterations a RMS of 8.0 was achieved. The fit curves are plotted in figure 6. The high RMS is mainly caused by static shift of the TE mode of site PB01. We observe the largest gradient of decreasing apparent resistivity approximately between 100 and 250 km depth. From 250 to 400 km the gradient is smaller and from approximately 400 to 550 km the electrical resistivity shows nearly constant values of approximately 5 Ωm.

Discussion

Processing of 150 subsequent days of continuous MT data results in MT transfer functions with periods from 10 to 100,000 seconds. A strong split up between TE and TM modes is caused by the Pacific Ocean. The 2D forward modelling also indicates that the phase transition zone as suggested by Utada et al. (2003) is reflected in the MT transfer functions at periods between 20,000 to 100,000 seconds.

Preliminary 2D inversion results of apparent resistivities and phases of two IPOC monitoring sites are generally in agreement with the previous geophysical studies. The strong gradient of electrical

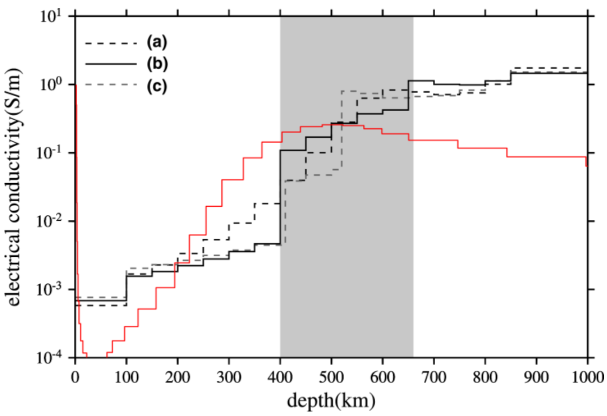

Figure 7: Conductivity values extracted from the 2D inversion model (Figure 5) derived as a vertical column between the two sites (red curve) compared to 1D inversions carried out by Utada et al. (2003) where (a) is unconstrained, (b) is constrained with contrasts at 400 and 660 km depths and (c) is also constrained with contrasts at 400, 550 and 650 km depths. Modified after Utada et al. (2003).

resistivity between 100 and 250 km depth could indicate the transition from the lithosphere of the down going Nazca plate to the asthenosphere (e.g. Giese et al., 1999). Between 400 and 550 km depth, which represents the upper part of the mantle transition zone, a nearly constant apparent resistivity of approximately 5 Ωm is observed. The semi-global reference model by Utada et al. (2003) shows a similar constant value of electrical conductivity in this depth range (Figure 7). In our inversion model, the minimum value of 4 Ωm is reached at 550 km depth.

References

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